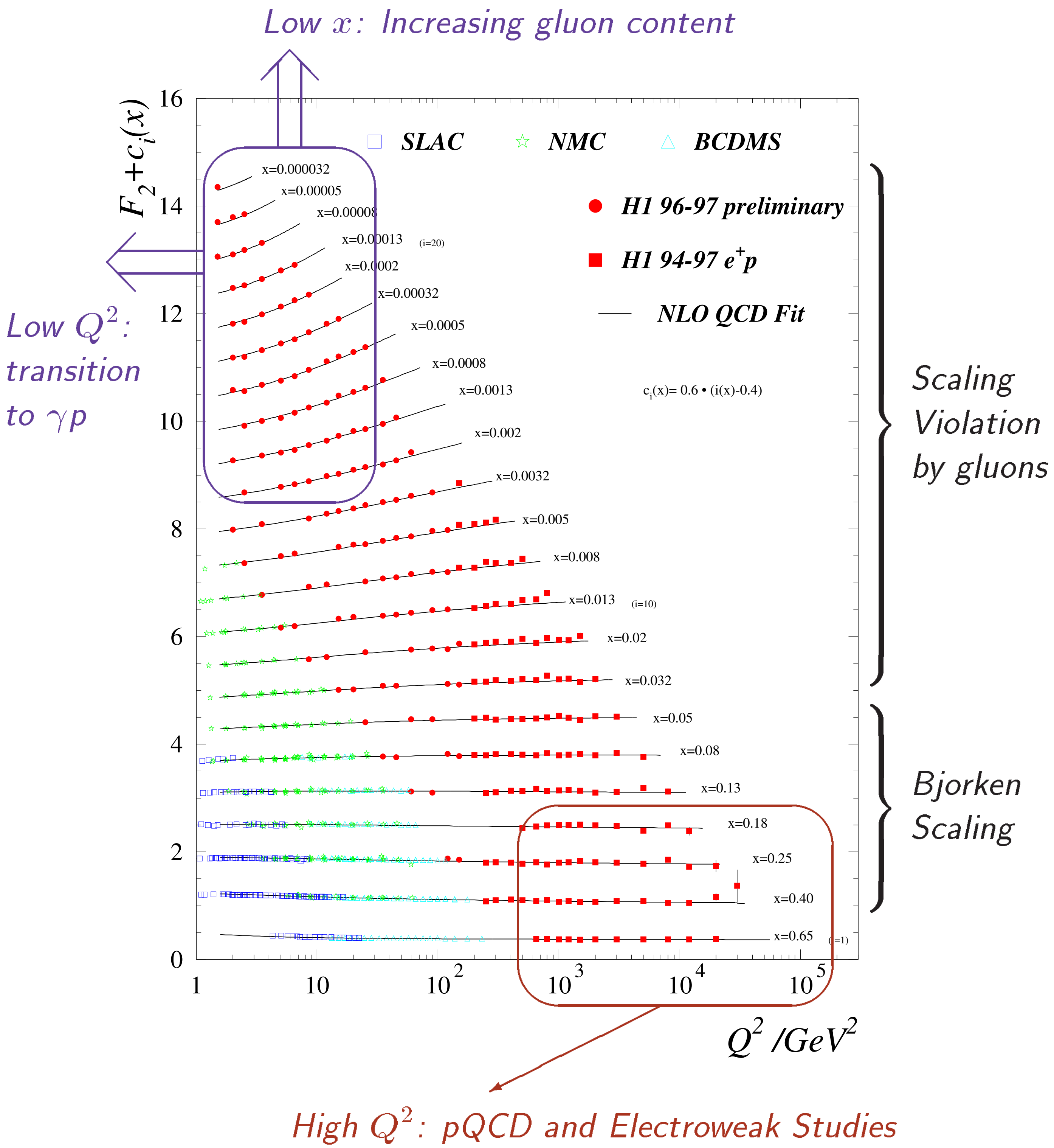
# STRUCTURE FUNCTIONS from HERA

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QCD00, 7 July 2000

# SF in Deep Inelastic Scattering

4-momentum transfer:

$$Q^2 = -q^2 = -(k-k')^2$$

Parton Momentum:

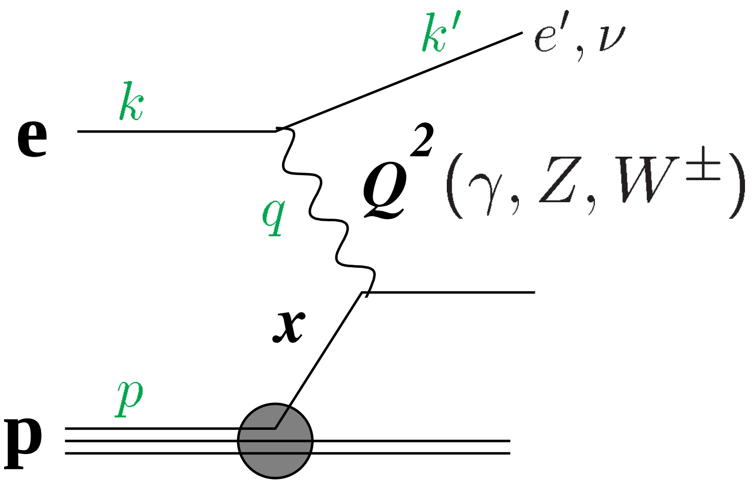
$$x = \frac{Q^2}{2p\cdot q}$$

Energy Transfer:

$$y = \frac{p\cdot q}{p\cdot k}$$

$\gamma^*$P center-of-mass:

$$W^2 = (q+p)^2 \simeq \frac{Q^2}{x}(1-x)$$




$$\frac{d^2\sigma^{e^\pm P}}{dx dQ^2} = \mathcal{K}\left[Y_+ F_2 \pm \underbrace{Y_- x F_3 - y^2 F_L}\right]$$

Only significant at high-$y$ (high-$x$)

$$Y_\pm = 1 \pm (1-y)^2$$

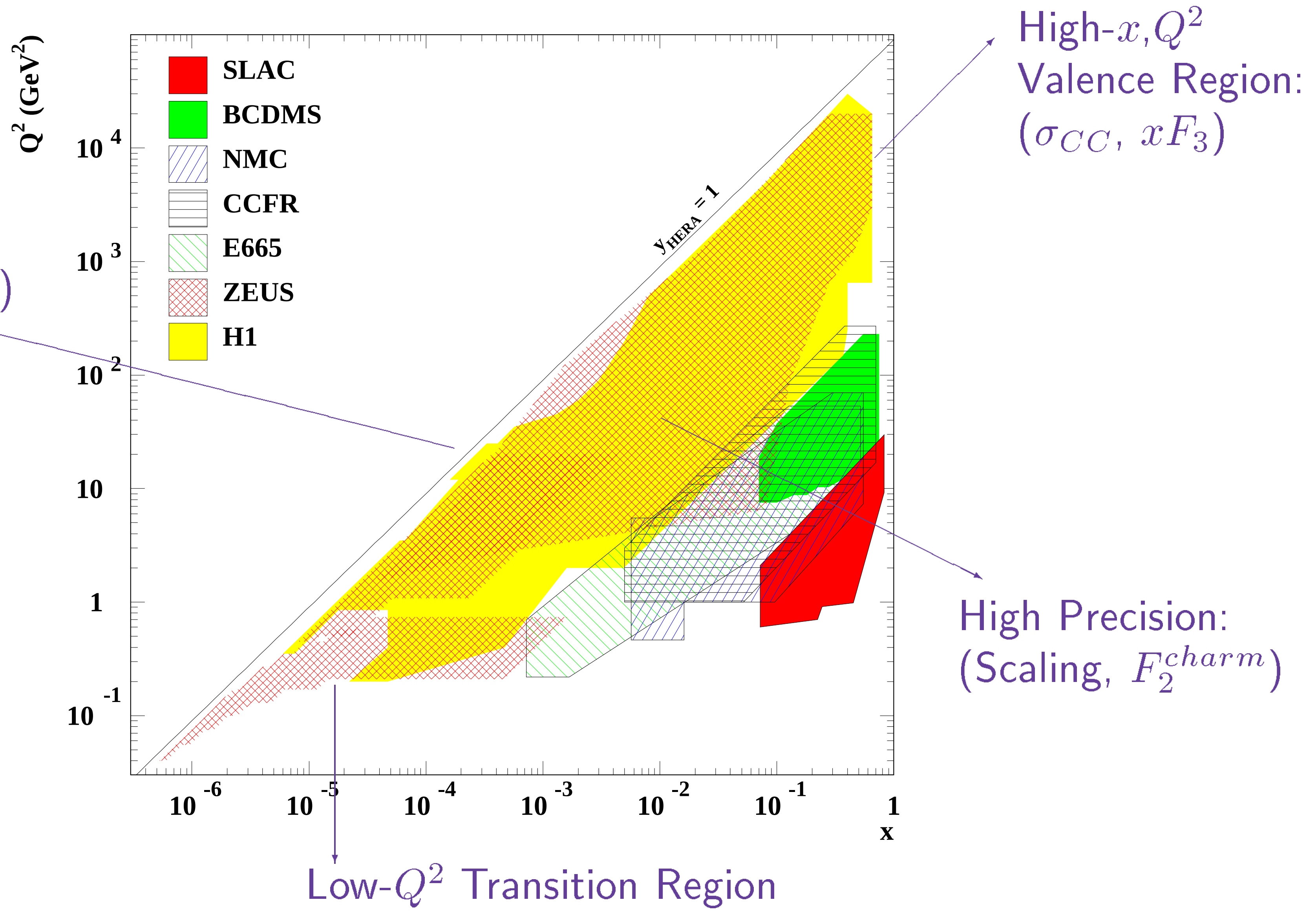
$$\mathcal{K}_{NC} = \frac{2\pi\alpha^2}{Q^4 x}$$

$$\mathcal{K}_{CC} = \frac{G_F^2}{4\pi x}\left(\frac{M_W^2}{M_W^2 + Q^2}\right)^2$$

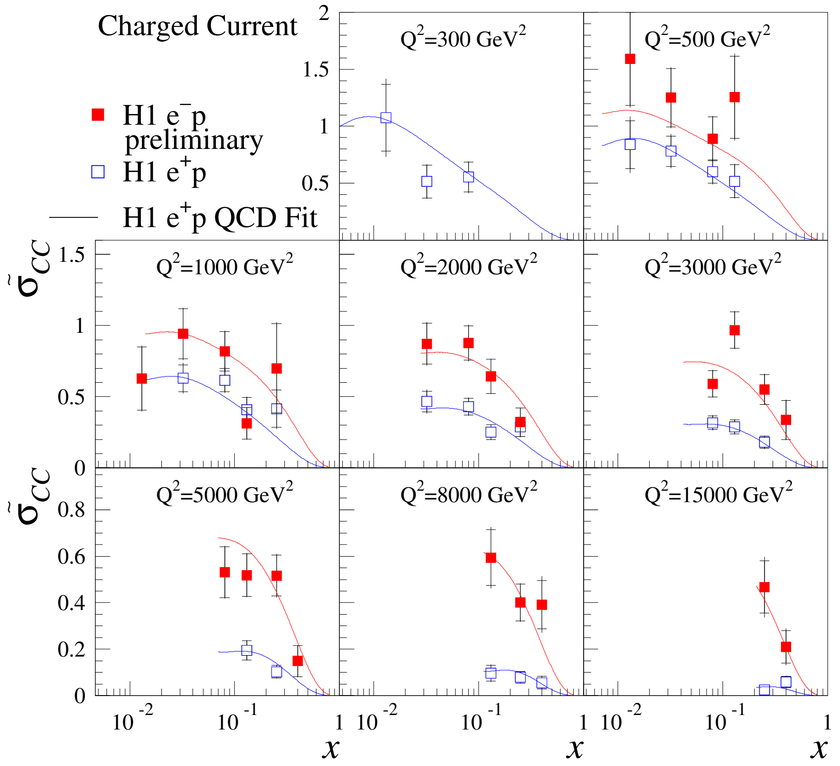
**Reduced Cross Section:**

$$\boxed{\tilde{\sigma}^\pm \equiv \frac{1}{\mathcal{K}Y_+}\frac{d^2\sigma^\pm}{dx dQ^2} \simeq F_2}$$

# HERA Kinematics

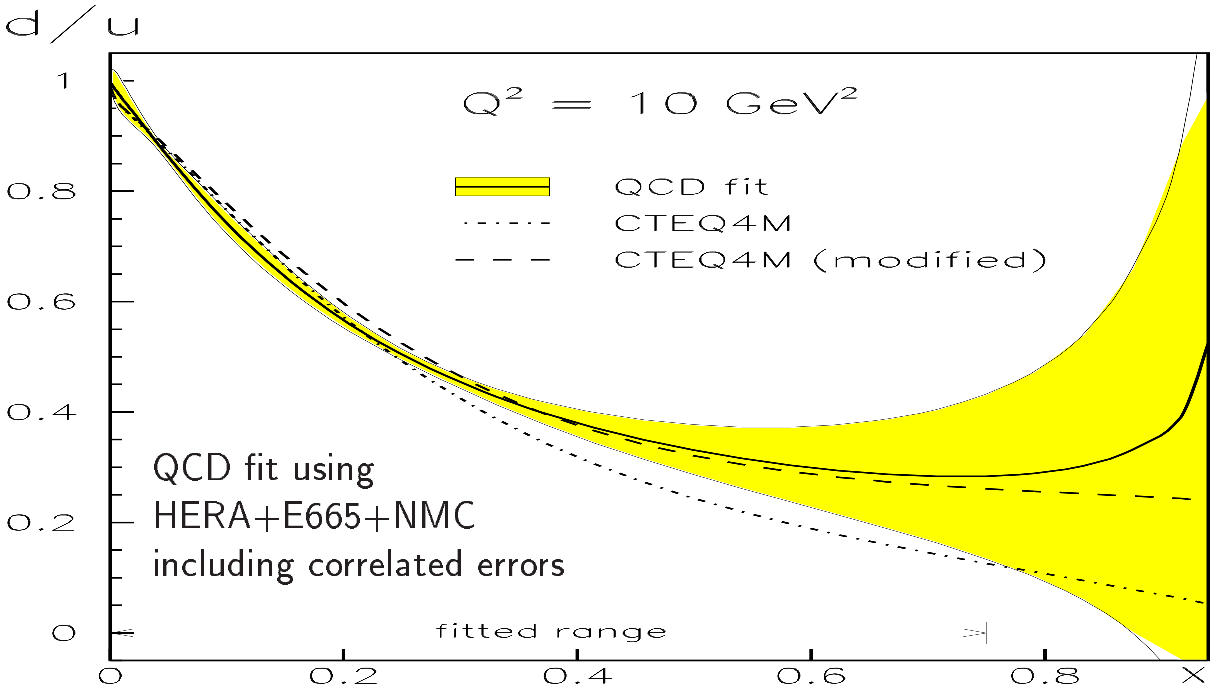


# High-$Q^2$ Charged Current




$$\tilde{\sigma}_{CC}^{e^-P} = x\left(u + c + (1-y)^2(\bar{d} + \bar{s})\right)$$

$$\tilde{\sigma}_{CC}^{e^+P} = x\left(\bar{u} + \bar{c} + (1-y)^2(d + s)\right)$$

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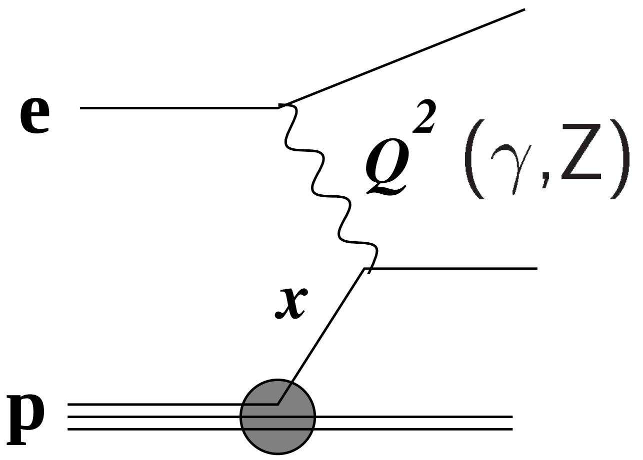
# $F_2$ from Neutral Current DIS




$$\frac{d^2\sigma^{e^\pm P}_{NC}}{dxdQ^2} = \frac{2\pi\alpha^2}{Q^4 x}\left[Y_+ F_2^{NC} \pm Y_- xF_3^{NC} - y^2 F_L^{NC}\right]$$

$x\sum A_f(Q^2)[q+\bar{q}]$

Couples to all quarks

Longitudinal Cross Section

Sensitive to Sea and gluons

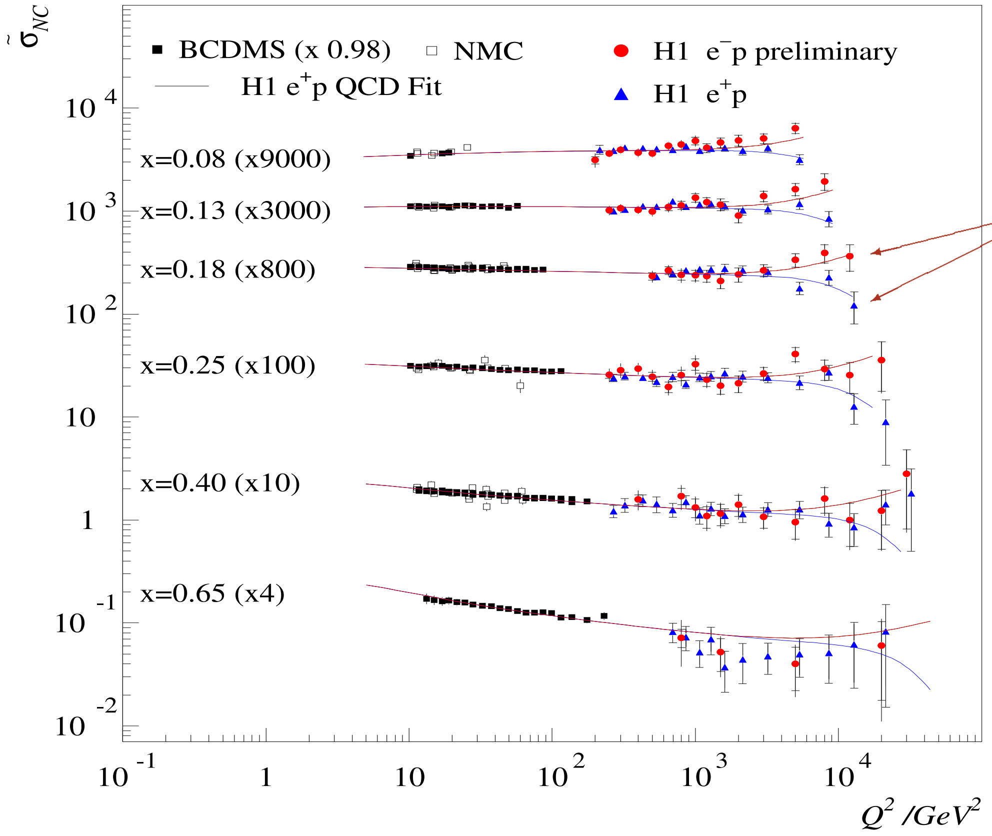
$\propto \frac{1}{4sin^2\theta_W cos^2\theta_W}\frac{Q^2}{Q^2+M_Z^2}$

Parity Violation

**Reduced Cross Section:**

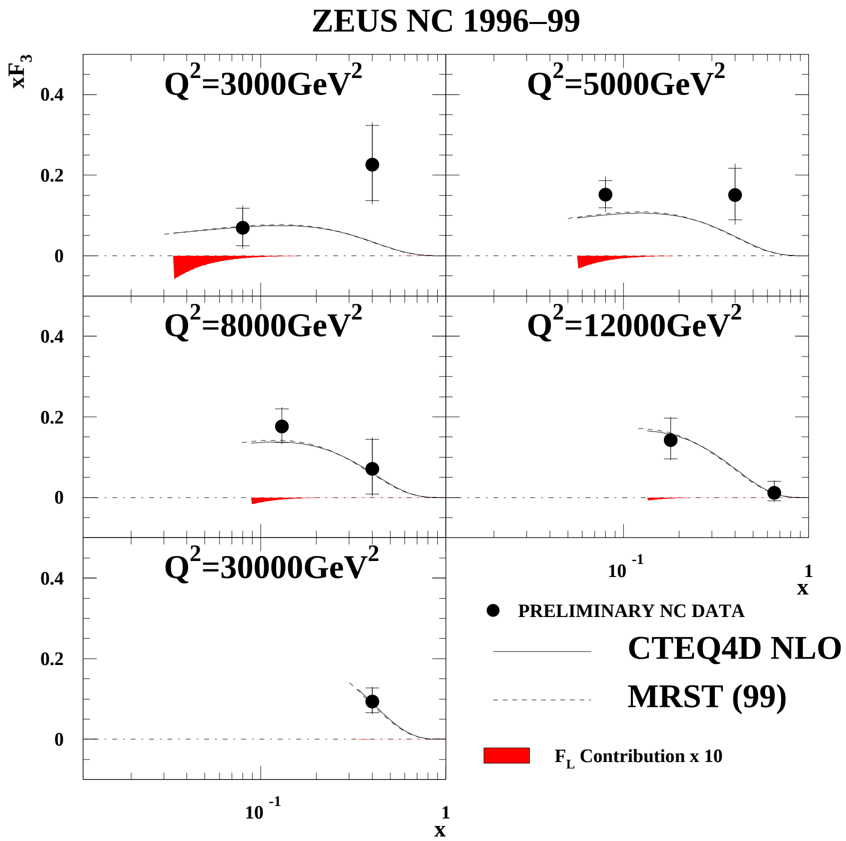
$$\tilde{\sigma}^{\pm}_{NC} \equiv \frac{xQ^4}{2\pi\alpha^2}\frac{1}{Y_+}\frac{d^2\sigma^{NC}}{dxdQ^2}$$

# High-$Q^2$ in Neutral Current ($xF_3$)

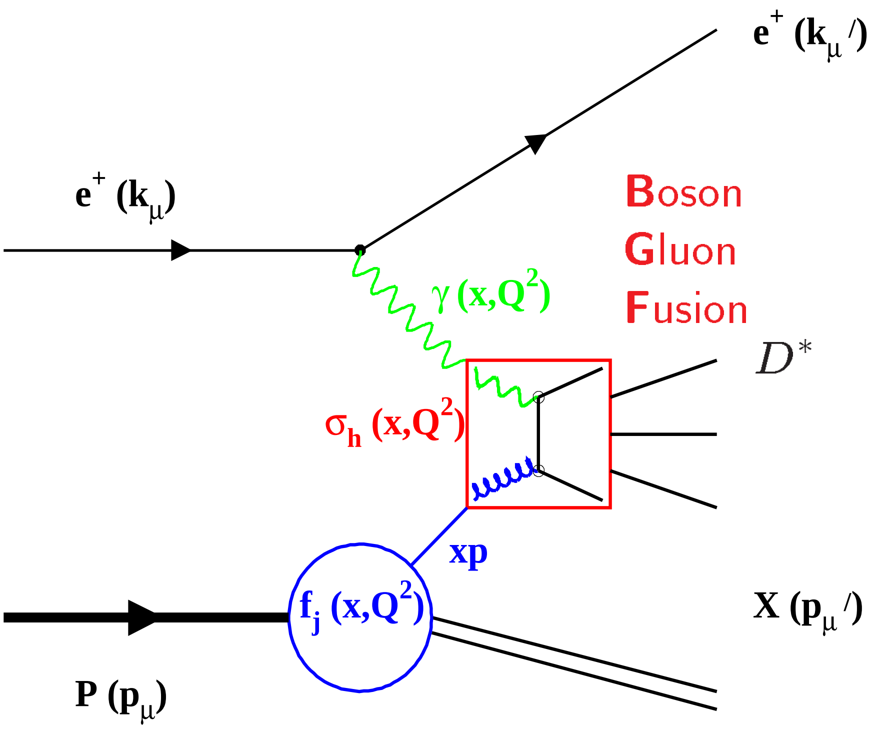



Parity violation clearly visible

- First extraction of $xF_3 \simeq \tilde{\sigma}^- - \tilde{\sigma}^+$ from bare proton
- Error limited by small electron sample: $\mathcal{L}^- < \frac{1}{2}\mathcal{L}^+$
- Consistent with QCD calculations



# Charm in $F_2$ – Scale for pQCD




$\boxed{\text{Very effective test of QCD}}$

Measure Inclusive $F_2$

Extract $xg(x)$

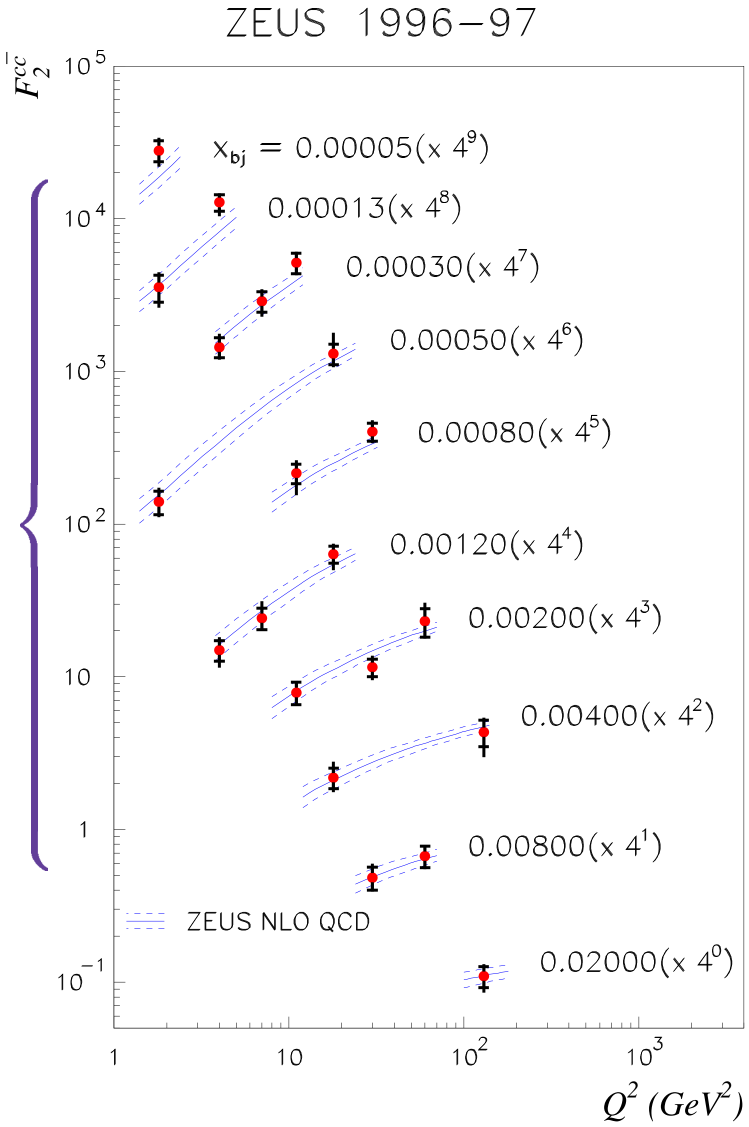
Measure visible $D^*$

Extrapolate to full Kinematics

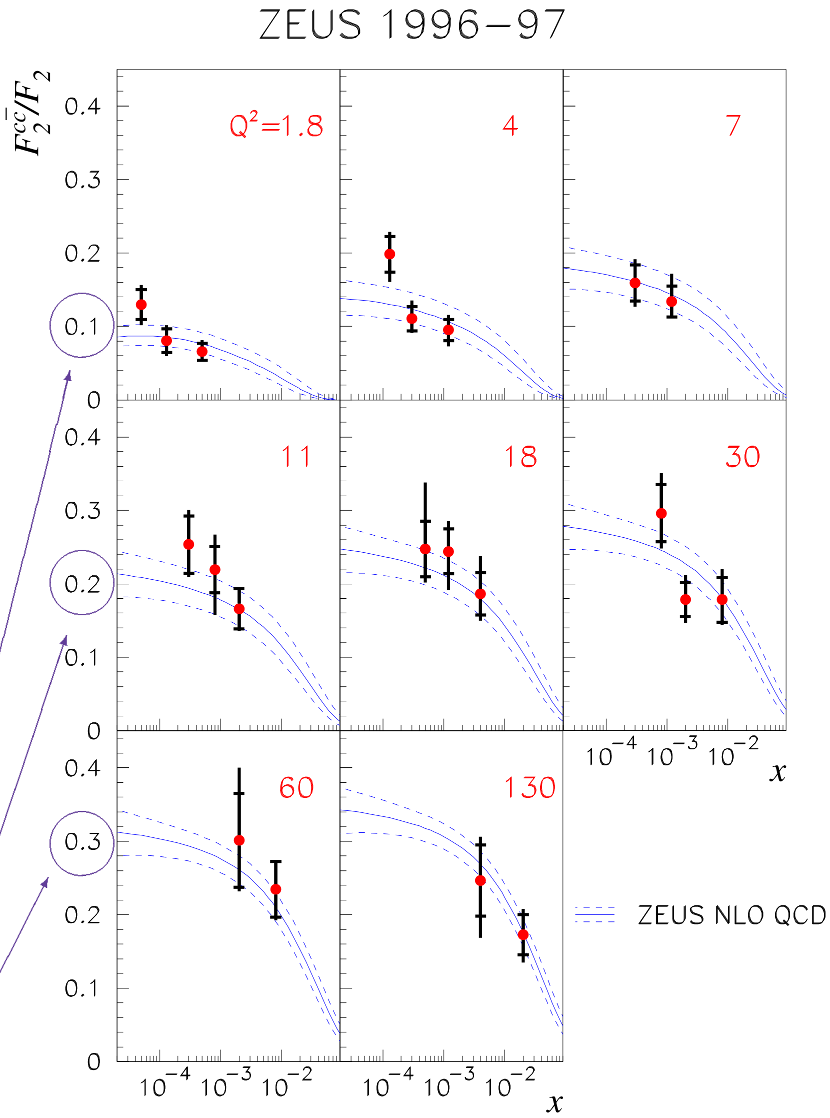
Calculate $xg(x) \otimes$BGF $\longleftrightarrow$ $\sigma^{C\bar{C}}$

$\boxed{F_2^{charm}}$

# $F_2^{charm}$ Results




*Stronger Scaling Violation* $\Rightarrow$ *gluons*




$\frac{\textit{glue}}{\textit{glue+sea}}$ *decreases as* $Q^2 \to 0$

# Extremes (low-$x$) – $F_L$ Extraction

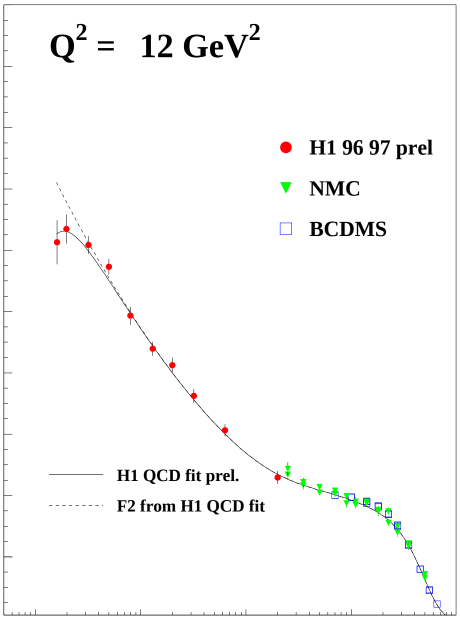
(Better Access to Sea)

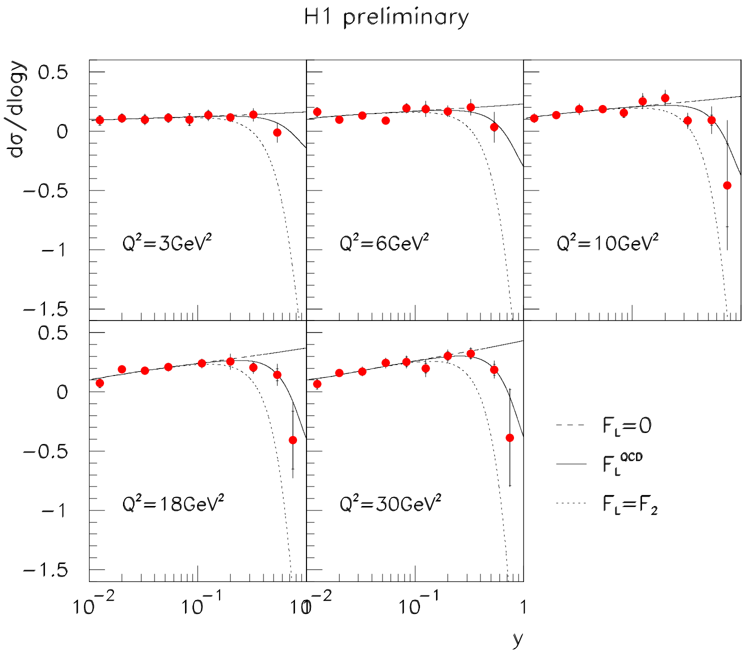
Subtraction Method: for high $y$

$$\tilde{\sigma} = \left( F_2 - \frac{y^2}{Y_+} F_L \right)$$

Exp Data

QCD Fit to data at intermediate kinematics



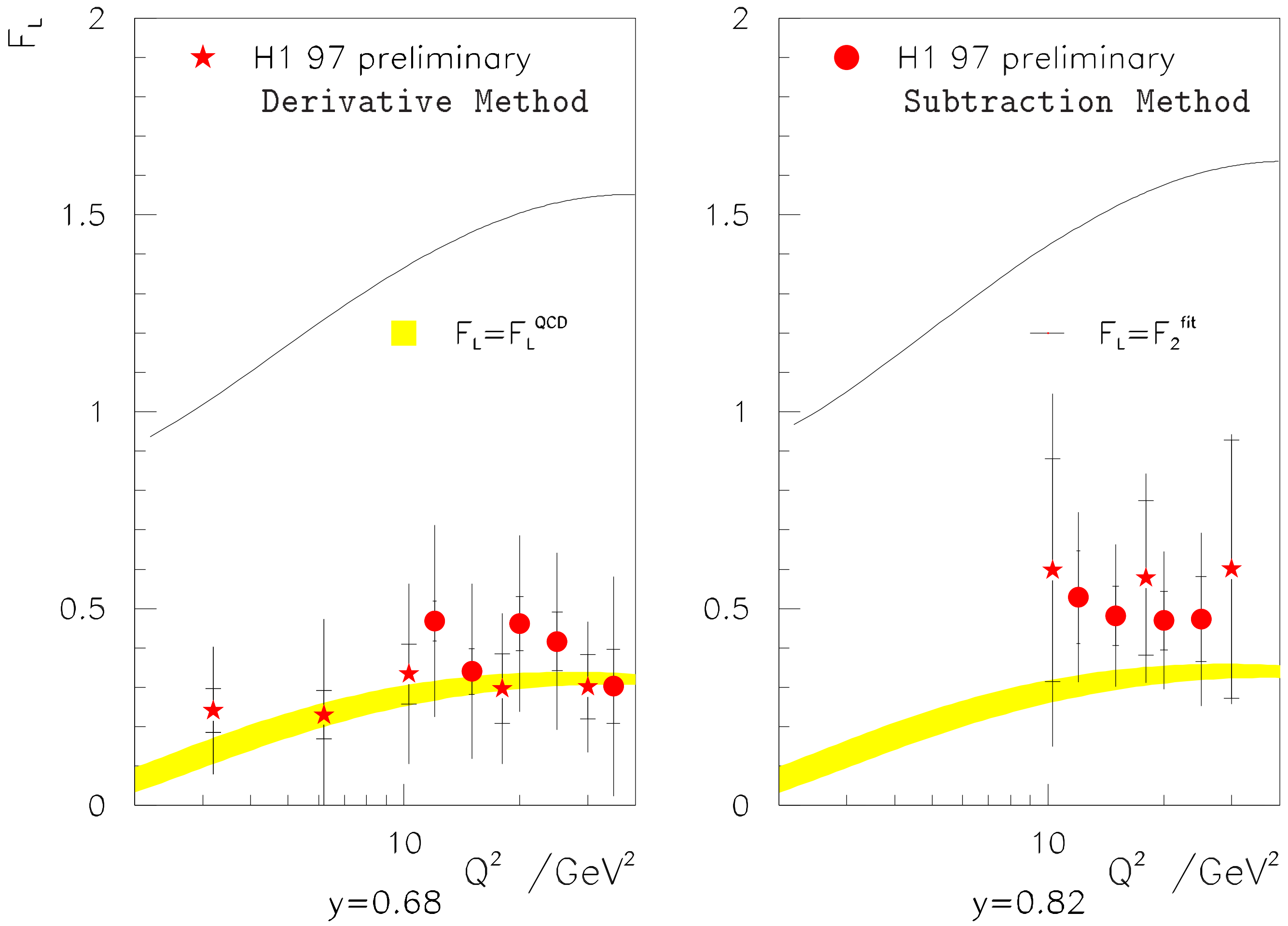

Derivative Method: for low $Q^2$

$$\frac{\partial \tilde{\sigma}}{\partial \log y} \simeq \frac{\partial F_2}{\partial \log y} - F_L \frac{2y^2(2-y)}{Y_+^2}$$

Assume

$$F_2 \sim x^{-\lambda} \sim \left(\frac{1}{y}\right)^{-\lambda}$$

# $F_L$ Results

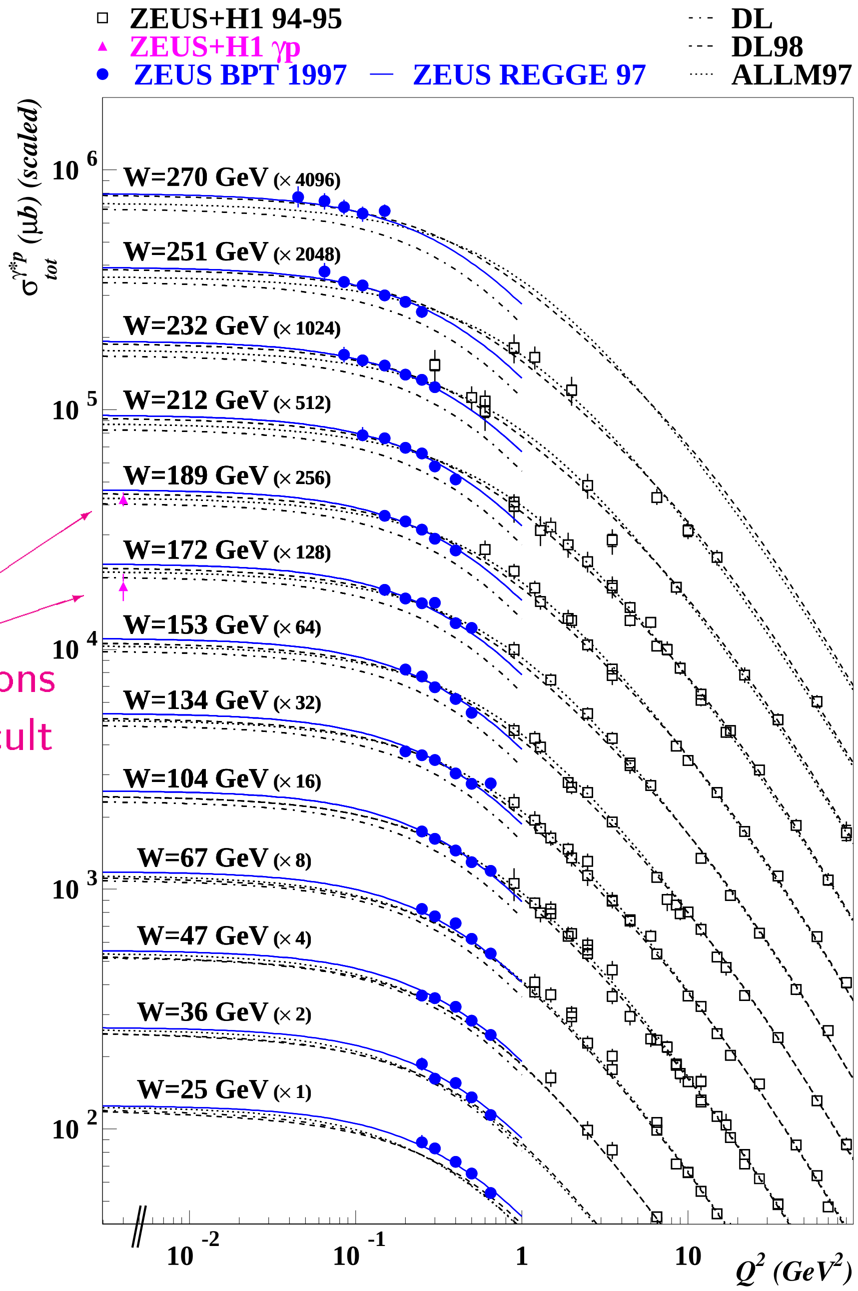



Two methods are consistent

$F_L$ compatible with QCD prediction
(tendency for $F_L > F_L^{QCD}$ at highest $y$)

# Extremes (low $Q^2$) – Transition to $\gamma$P

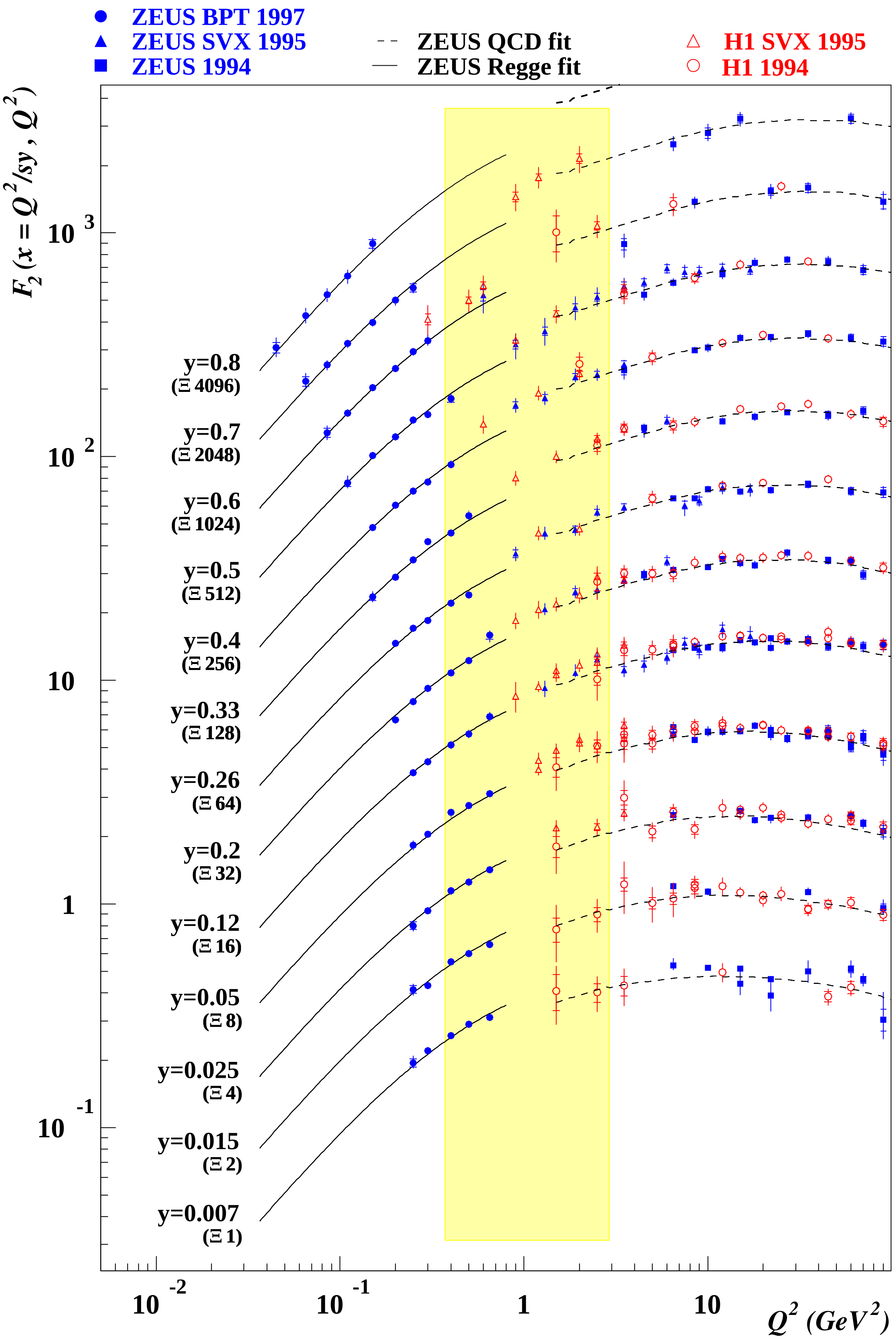
$$\sigma_{tot}^{\gamma^* P}(W,Q^2) \approx \frac{4\pi^2\alpha}{Q^2} F_2(x,Q^2) \approx \underbrace{\frac{M_0^2}{M_0^2+Q^2}}_{\text{GVDM}} \sigma_{tot}^{\gamma P}(W)$$




Extrapolations to $\gamma$P difficult

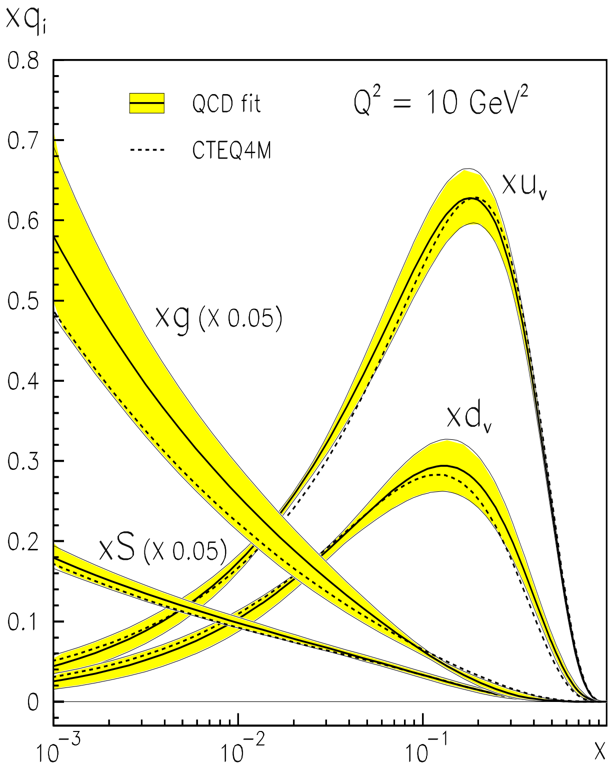
Regge $\Longrightarrow$ $\Longleftarrow$ pQCD

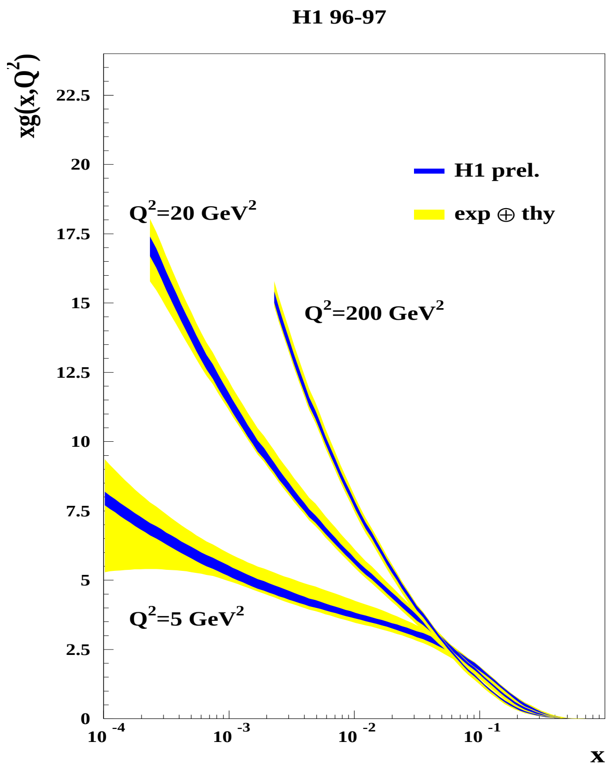
# Extremes (low $Q^2$) – *Critical* Region




Regge $\Longrightarrow$ $\Longleftarrow$ pQCD

# $F_2$ Pushing the Envelope




- HERA achieves high precision:
  Systematics and Theory dominate many errors

- NLO QCD describes data well even down to very low scales $Q^2 \sim 1$ GeV$^2$ (accident?)

- Current and future data will allow more constraint on the extreme regions (low $x$,$Q^2$ and high $x$,$Q^2$)